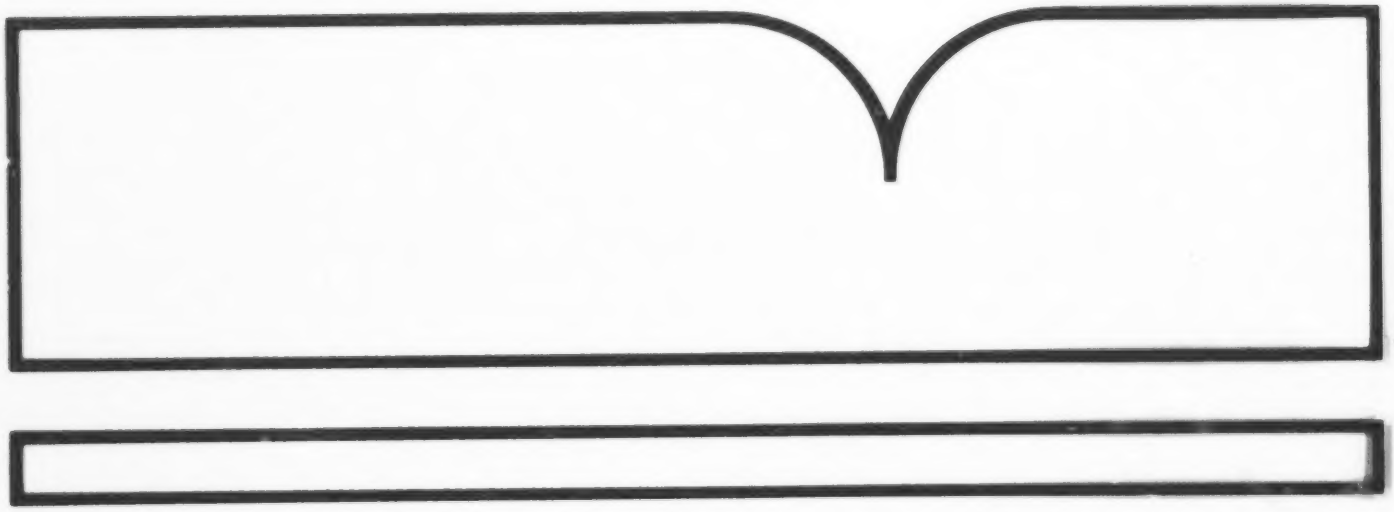
PB86-118502

Environmental Assessments from Simple Test Systems and a Microcosm Comparisons of Monetary Costs

(U.S.) Environmental Research Lab.
Narragansett, RI

Oct 85



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1. REPORT NO. EPA/600/D-85/270	2.	3. PB86-118502
4. TITLE AND SUBTITLE: ENVIRONMENTAL ASSESSMENTS FROM SIMPLE TEST SYSTEMS AND A MICROCOSM: COMPARISONS OF MONETARY COSTS		5. REPORT DATE: October 1985 6. PERFORMING ORGANIZATION CODE:
7. AUTHOR(S): K.T. Perez and G.E. Morrison		8. PERFORMING ORGANIZATION REPORT NO.: ERLN-590
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S.EPA, ERL-Narragansett South Ferry Road Narragansett, RI 02882		10. PROGRAM ELEMENT NO.: AARB1A 11. CONTRACT/GRANT NO.: NA
12. SPONSORING AGENCY NAME AND ADDRESS: Same as above		13. TYPE OF REPORT AND PERIOD COVERED: Symposium Proceedings 14. SPONSORING AGENCY CODE: EPA/600/05

15. SUPPLEMENTARY NOTES: IN: Multispecies Toxicity Testing, J.Cairns, C.H Ward, and B.T. Walton Eds., SETAC Special Publications Series, Pergamon Press. NY,1985. (PROC. SYMP. Blacksburg, VA,May 15-18,1983) pp.89-95

16. ABSTRACT

Monetary costs were compared for the environmental assessments of an organic chemical using a test microcosm which simulated a real environment and a suite of simple test systems currently used. It was found that the microcosms were cost-competitive with the simple test systems. In addition, it is argued that the differences in the form and quality of information generated from these two types of test systems provides further incentive to use complex, site-specific microcosms in the environmental assessment process.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

18. DISTRIBUTION STATEMENT: DISTRIBUTE TO PUBLIC	19. SECURITY CLASS *(This Report)*: UNCLASSIFIED	21. NO. OF PAGES: 9
	20. SECURITY CLASS *(This page)*: UNCLASSIFIED	22. PRICE

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Multispecies Toxicity Testing,
J. Cairns, C. H. Ward, and B. T. Walton,
Eds., SETAC Special Publication Series,
Pergamon Press, NY, 1985, pp 89-95,
Chapter 9.

EPA/600/D-85/270
October 1985

Chapter 9
Environmental Assessments from Simple Test Systems and a Microcosm: Comparisons of Monetary Costs

Kenneth T. Perez and
George E. Morrison

INTRODUCTION

Ecological systems have been and are being exposed to anthropogenic chemicals. Current environmental assessments of such chemicals are primarily based upon data derived from "simple," isolated, test systems. These test systems are designed to measure either various physical and chemical processes (e.g., water solubility, microbial degradation, partitioning, etc.), and/or dose-response relationships of single biological organisms (e.g., bioassays). However, the National Research Council [1] argued that "it is not possible to characterize the response of any (eco) system to general or specific perturbations solely from the knowledge of the response of a few component parts . . . " (p. 12) because such systems "are not sensitive to interactions among species or to indirect influences that can dominate in complex systems . . . " (p. 64). Furthermore, the Council [1] noted that microcosms, designed to simulate natural systems or portions therefrom can overcome many of these limitations because they "allow for an accurate definition of physical, chemical, and biological characteristics (of natural systems) . . . " (p. 66). These viewpoints were recently supported by a microcosm study [2] which showed that the combined effect of biotic complexity and temporal heterogeneity qualita-

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tively and quantitatively influenced the environmental assessment of a synthetic phthalate ester in a marine ecological system. If microcosms, which simulate natural environments, are more accurate than bioassay and other simple test systems, the question immediately arises as to why they are not used more often in the environmental assessment process.

One of the major reasons why complex microcosms are not routinely used when environmental assessments of chemicals are developed is that they are costly. Some researchers [3] have suggested that microcosms are more costly to operate than single species tests [3, p. 97]. Others [1] however, have claimed that microcosms are capable of providing more accurate and pertinent information "with minimal effort and with no greater expense than that associated with well-designed single species tests" [1, p. 66]. However, neither of these recent review studies provided any supportive cost information.

This study will attempt to compare the monetary cost for environmental assessments of a specific chemical, Di-2-ethylhexyl phthalate (DEHP), using a complex microcosm and a suite of simple test systems.

METHODS

Development of Environmental Assessment

An environmental assessment should incorporate the fate of a chemical (e.g., partitioning, degradation, bioaccumulation, etc.) and the ecological effects resulting from the subsequent exposure concentrations. A microcosm study, which simulates natural environments, is capable of generating such chemical fate and ecological effect information in a single test system. However, the current suite of simple test systems such as the 42 tests promulgated by the U.S. Environmental Protection Agency, Office of Toxic Substances [4, 5] are designed to measure separately and singularly various physical and chemical processes (e.g., water solubility, partition coefficient) and biological phenomena (e.g., toxicity, degradation, bioconcentration) usually for single species of organisms. As a result, an environmental assessment of a chemical using such simple test systems will require data from more than a single test system. In short, many individual tests, which generate specific chemical fate and ecological effect information, will be necessary along with a scheme to integrate all the information into a realistic environmental assessment.

Choice of Studies for Cost Comparisons

As indicated above, there are many specific, isolated test systems from which an environmental assessment can be developed. Because our choice of any subset and associated costs would be arbitrary, we used the total cost fig-

ures associated with the suite of test systems that the Chemical Manufacturers' Association (CMA) [6] selected to develop an environmental assessment of phthalate ester. The costs derived from the CMA study, which used a subset of the simple test systems alluded to, were compared to the costs of a recent microcosm study [2, 7]. The CMA study was chosen because: (a) it was supported by a broad, diverse and representative cross section of the individuals responsible for assessing the environmental hazards of chemicals, namely the commercial chemical industry; (b) the time period at which both studies were performed was similar (ca. 1980–1982); and (c) the chemical studied, a phthalate ester, was identical to the microcosm study and analytical costs should therefore be comparable.

Cost Analysis: Complications, Restrictions, and Assumptions

It was not possible to compare directly the total costs for the CMA and microcosm studies because the CMA study was performed by commercial testing laboratories and the microcosm study by a federal laboratory. As a result, the absence of profit and lower overhead charges in the latter laboratory precluded direct cost comparisons. However, the costs for the two studies could be compared provided the overhead and profit charges of the CMA study were added to the direct costs (i.e., salaries and supplies) of the microcosm study. Unfortunately, the only cost information available for the CMA study was the total cost. That is, the actual overhead and profit charges were unavailable. As a result, these charges had to be estimated and then added to the direct costs of the microcosm study.

According to Kurtz [8], commercial overhead charges for bioassay tests range between 50–250% of direct costs whereas profit charges range between 8–30% of actual costs (sum of direct costs and overhead charges). We have assumed that the overhead and profit charges for the physical and chemical tests are similar to the bioassay tests. The total costs of performing the microcosm study at commercial testing laboratories were computed by taking direct costs of the microcosm and then adding Kurtz's [8] best estimates for current commercial overhead and profit charges. This total cost figure could then be validly compared to the total cost figure for the CMA study.

Another complication in the comparison was incomplete cost information for the CMA study. Specifically, the study is composed of two phases [6]. The total costs for Phase I are known, but only an estimate for Phase II (i.e., Phase II total costs $>>$ Phase I) is available since this portion of the study will not be implemented until later this year [H. B. Lockharte, Eastman Kodak Corporation, NY, personal communication, 1983].

Last, it should be pointed out that the cost analysis and subsequent comparisons do not explicitly consider initial capital expenditures for major equip-

ment. It was assumed the payback of these expenditures for both studies was realized in overhead charges.

Type of Environmental Assessment Information

The type of technical information obtained in both assessment studies is both similar and dissimilar. We have not attempted to estimate the costs associated with the appropriateness of such measurements. Rather, our position is that both studies have made decisions as to what should be measured based upon various arbitrary considerations. However, the fundamental similarity between the two studies is that each feels the data base chosen is adequate to assess the environmental hazards of this particular chemical, DEHP.

RESULTS

The direct costs (salaries and supplies) for the microcosm study of DEHP are presented in Table 9.1. Seven individuals were involved in the study, two chemists and five biologists with salaries ranging from $7.30 to $15.41/hr as of October 1980.

The addition of industrial overhead and profit charges to the direct costs and actual costs, respectively, of the microcosm study revealed that the latter study was cost-competitive with the CMA study (Table 9.2). Specifically, the estimated total costs for the completion of the microcosm study by a commercial testing laboratory ranged between $73,152 and $213,362. The

Table 9.1. Total Direct Costs for the Chemical Fate and Ecological Effects of Di-2-ethylhexyl phthalate (DEHP) in a Marine Microcosm During the Winter and Summer Seasons

	SYSTEM OPERATION	BIOLOGICAL SAMPLES	CHEMICAL SAMPLES	DATA REDUCTION AND ANALYSIS
Supplies (per experiment)	$50.00	$124.00	$2,620.00	$50.00
Salaries (per experiment)	$1,754.00	$5,040.00	$8,240.00	$4,700.00
Subtotal direct costs per experiment	$1,804.00	$5,164.00	$10,860.00	$4,750.00
Total direct costs for single-seasonal experiment		Labor = $19,734 Supplies = $2,844 $22,578		
Total direct costs for two-seasonal experiment		$45,156		

Table 9.2. Comparison of Information and Associated Monetary Commercial Costs for Environmental Assessments of a Phthalate Ester Di-2-ethylhexyl phthalate (DEHP) Derived from Simple Test Systems (CMA Study) and a Microcosm System

VARIABLE	INFORMATION	COST
CMA Assessment		
Phase I		
Water solubility Octanol/water partition coefficient Vapor pressure	Environmental fate	$2,700
Shake flask biodegradation Activated sludge biodegradation		$6,300
LC_{50}, static – six organisms LC_{50}, flow – three organisms *Daphnia magna* reproduction	Aquatic toxicity	$53,400
	Subtotal = $62,400[a]	
Phase II		
Embryo-larval partial Chronic – two organisms Oyster toxicity – 96 hr Shell deposition	Aquatic toxicity	–
Uptake and depuration – organisms	Bioconcentration	–
Aerobic aquatic metabolism Freshwater ecosystem	Environmental fate	–
Soil sediment adsorption Soil TLC	Mobility	–
	Subtotal > > $62,400	
	Total > > $124,800	
Microcosm Assessment		
Dynamics of parent plus breakdown products in: Gas phase Surface microlayer Water column Tissues – 10 organisms Sediments Tank surfaces	Environmental fate (transport plus partitioning) and bioaccumulation (food plus exposure media)	$26,508
Nutrient water column dynamics Bacterial water column dynamics Phytoplankton dynamics Zooplankton plus transient larval forms dynamics Benthic community nutrient flux dynamics Benthic density dynamics	Ecological effects (structural plus functional)	$18,648
	Direct costs	$45,156
	Industrial overhead charges (50–250% of direct costs)	$22,578–$112,890
	Actual cost	$67,734–$158,046
	Industrial profit charges (8–30% of actual cost)	$5,418–$55,316
	Total	$73,152–$213,362

[a]Average cost per phthalate (14 tested).

lowest approximation of the total costs for the CMA study, $124,800, falls approximately midway between this price range. That is, the microcosm assessment if performed commercially would be less or more expensive than the CMA assessment by approximately a factor of 1.7.

It is important to note that the "freshwater ecosystem" test of Phase II in the CMA Study (Table 9.2) is not a field or complex microcosm study. Rather, the test involves the measurement of relative persistence in water and hydrosoil only.

DISCUSSION

We have shown that the monetary costs of environmental assessments of a chemical utilizing a single microcosm system and a series of simple bioassay and physico-chemico test systems are, at the worse case, effectively equivalent. However, the direct costs for the microcosm study could be reduced further since the original study was primarily a research and development effort. That is, no attempt was made to minimize replication density in the experimental design or the frequency and number of variables measured. In addition, seasonal effects were tested because the geographic location of the natural system being simulated was in a north temperate ecosystem—Narragansett Bay, Rhode Island. Therefore, two seasonal time periods were simulated, doubling the final data base. As a result of all of these conditions, the total costs of the microcosm study presented should be considered as overestimates of the total costs a commercial contracting company would incur if it: (a) reduced the microcosm data set to a minimum, and (b) simulated natural environments in geographic locations that do not exhibit large seasonal effects.

Another important cost factor not considered in this cost comparison is the quality of information developed from microcosms and simple test systems. In simple test systems, measurements of various elements of a process, e.g., chemical partitioning and toxicity are made: (a) indirectly and (b) independently of other system-level chemical, physical, and biological interactions and complexities. These two constraints, therefore, add a high degree of uncertainty to the accuracy of measurement since the ability to relate laboratory results to a natural system is highly subject to question. On the other hand, when efforts have been made in the unperturbed case to simulate natural forms and levels of complexity in experimental microcosms, two results have occurred. First, direct, as opposed to indirect, measurements of various processes and variables are possible. Second, many of the biological, chemical and physical events observed in the natural system are similarly expressed in the experimental microcosms [see references 9 and 10]. These two findings mean that the measurement of perturbed data from these and similar microcosms are more easily and confidently relatable to the natural ecosystem be-

ing simulated. We are unable, at this time, to determine the cost benefits associated with the degree of certainty for data derived from microcosms and simple test systems. However, we would argue that such cost benefits are greater for the former than the latter.

Acknowledgments—Dr. Thomas Weaver, Department of Resource Economics, University of Rhode Island, and Drs. Vincent Nabholz and Francis Benenati, Office of Toxic Substances, U.S. Environmental Protection Agency, graciously provided technical information and helpful comments for the study.

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